Hypervideo as a tool for communicating Mathematics

Maria Haydée Morales

1 Introduction

On the World Wide Web, hypertext has provided a powerful mechanism for integrating multimedia as information based on text augmented with image, sound and video elements. However, a broader basis is necessary to structure and integrate a video-centric medium, where the notion of hyperlinks must be redefined to consider the spatial and temporal aspects of video. New interaction paradigms must be developed to navigate in a hyperlinked network, video-driven content called Hypervideo.

This work is devoted to the exploring of the mechanisms that allows us to construct this new kind of video-centered presentation making possible enriched forms of navigation, in special, allowing a real navigation through the video. Integrating the temporal dimension on a presentation has been determinant for this purpose.

We will study hypervideo particular features, potential uses, tools for its development and production process. In what concerns to potential uses, we will focus on the communication of mathematical concepts.

We present in chapter 2 the problematic of communicating Mathematics and we introduce Mathematical Visualization as a technique that can help students on the understanding of abstract ideas. Graphics and video images have been a medium for presenting these visualization results. However, specially in the case of video images, if they are seen in a passive way, their content is not optimally absorbed by the student as its does not provide him time to reflect. This reflection time is essential when trying to understand abstracts concepts. We present hypervideo as a better way to see video images than with VCR. We will explore it as a powerful tool to teach mathematics using the power that video images already have and enriching this content with additional information provided by text, still images, animation and many other kind of media.

We present in chapter 3 a general hypermedia model and then our hypervideo model, as a special case of the first one.

We will discuss some of the tools that allow constructing this sort of presentation but we will focus on SMIL (pronounced “smile”), Synchronized Multimedia Integration Language. This language is presented in chapter 4. It became a W3C recommendation on 15th June 1998 and has been developed by the SYMM working Group that includes Netscape, Real Networks, Philips, Digital Equipment and others. We present some of the advantages of SMIL as, for example, support for adaptive and independent content. We will also describe some of the players that already support this language like RealPlayer, Grins and QuickTime.

In chapter 5, we present the problematic of producing a very new hypermedia product and try to give some general steps when producing a hypervideo. We present, as our
study case, the construction of a sample of hypervideo based on the video production “The Story of Pi” by Prof. Tom M. Apostol from the California Institute of Technology and which has already been translated into Portuguese by the project “Matemática em Ação” of CMAF–University of Lisbon [28]. This video is already a helpful tool on teaching mathematics but we will show how the communication of the content can be improved by transforming it into a hypervideo.

Our purpose with this hypervideo is to allow the student to navigate through the video, giving the student the option of going through it in a non-linear way and going deeper in many points that were not exhaustively exploited on the video.

Because mathematics is not a national topic but a rather a universal one, this sort of hypervideo production is not focused in one specific country and could perfectly be done in cooperation with diverse institutions, inside Europe and outside. This is a product that can perfectly be done multilingual as SMIL allows the construction of presentations with adaptive content, that is, the same presentation could be transmitted with English or French captions and presented in the language the user prefers, configured in the player or the browser.

Finally, we present our conclusions and further directions for research in chapter 6.

2 Motivation

2.1 Communicating mathematical concepts

We have seen in the last few years several efforts by diverse institutions on improving the image that mathematics has with the general public. We have also witnessed several activities, specially in year 2000 — World Mathematical Year, to raise public awareness of Mathematics. However, we have also observed many failures on students progress in this field.

More than ever, we are aware that teaching mathematics is a difficult task and that most of the teachers have not been very successful on capturing their students attention or motivating them correctly.

Abstraction is an essential feature of Mathematics as it allows generalization of ideas and results. It is commonly held that mathematics began when perception of three apples was freed from apples and become the integer three [9]. In a more advanced stage, abstraction and symbolism has lead us to very important and general results. They have taken us much farther than our own conception of the real world could have taken us.

However, abstraction has made Mathematics a difficult subject to teach and study because most of students who are trying to understand a mathematical concept loose easily their motivation as they cannot see, touch or try what they are studying. One problem the students face when confronted to abstract ideas is that they need to make the inverse way from abstraction to concrete concepts. Concretization of ideas is very important in the process of learning.

Visualization is an important way of concretization of mathematical ideas. Mathematical Visualization is a new topic that has been developed inside mathematics in connection with the area of computer graphics to help overpass the obstacles that abstraction brings to the good understanding of many mathematical concepts. Visualization is the representation of ideas, principles or problems by images, and has always played an important role in both teaching and learning mathematics. Visual images make a much greater impact
than printed or spoken words and they are a very condensed way to present ideas or concepts.

Even if simple drawings have been used in mathematics for a long time with the only aid of simple devices, the last visualization developments have only been possible thanks to the intensive use of computers. Computers are perfect drawing instruments in geometry allowing to show objects that only exist mathematically. It is even possible to show as “real” the mathematical objects that do not have any possible existence in the “real world”.

2.2 The aid of mathematical software

Even if doing mathematics has frequently been regarded as a mental experience that barely needs some writing tools, it is not fair to say that mathematics is done totally in the head. Mathematics has been aided by many instruments and devices since the early history of Geometry and Arithmetic, with the ruler, compass and abacus up to present days with computers.

With the development of computer power three decades ago, many computations could be done in a very fast and exact way, opening new possibilities to mathematicians.

Not just mathematical research but also mathematics teaching have been helped in the last few year by the development of computer graphics and other graphical tools. Various software tools have been developed in order to make many mathematical topics more accessible to a broad public, including very young students.

2.3 The power of video for Mathematics

“Pictures can make both teaching and learning a pleasure. And educators agree that when a student has begun to learn and like it, half their problem is solved”

W. Disney

One of the best ways to show the results of visualization is through video images. Nevertheless, this is not the only use of video in education.

The power of video as an educational tool has been envisioned by many even in the very early stages of the motion picture. Thomas A. Edison saw the motion picture as being destined to revolutionise the educational system and in his own words “… in a few years it will supplant largely, if not entirely, the use of textbooks” (quoted in [31]).

Walt Disney also visualized motion picture, in the form of animated cartoon, as a mean to present the world in a different way. It is possible to get inside complex machines, to slow down their motion, show elements invisible for human eyes, in resume, it give us the possibility to show what our eyes in a natural environment could not see.

Video images handel mathematical concepts in a way that cannot be done only through text or still images as movement and sound introduce many components that help the learning process [2].

Many of the developments on computer graphics, visualization and on mathematical software (see [22]) are used to produce video material with mathematical content. Animated graphics are even richer forms of visualization as they make it possible to show the dynamic of some mathematical objects, that is, its transformation as time changes, and also other kind of changes in the object as some specific parameter changes. This is a tremendous help and a big advance on mathematics understanding.
2.4 The way we see video

In spite of all the predictions for the use of video as a fundamental educational tool and the great developments in the visualization field, video cassettes were not of much use at schools nor had had very much impact on mathematics education.

Video images (TV, videocassettes) are seen mostly in passive way. Unfortunately the simple visualization of a video is not enough for an optimized transmission of a concept. Mathematical concepts need reflection. They are not easy to absorb so the students need sometimes to stop and think, in other words, they need to have a “reflective moment”. Normal VCRs come with remote controls. However, in educational environments they are seen by more than one person and remote controls are not frequently used to stop or rewind to repeat a scene. Videos are mostly seen non-stop. So, here is where the problem arises. Even if a video is very well conceived, the way it has been seen at schools does not provide the student the necessary reflective moment, does not allow him or her to think about what is being seen, and therefore, there is no optimized concept transmission.

Besides this, sometimes it is also necessary to allow the student to find out more about what is being visualized in order to be able to understand better what comes next. The possibility to stop the video and read or see additional information should be regarded.

We need a media that allows and encourages interaction and that lets the student reflect. Another important requirement is to let the student move through the video not guided by seconds or minutes as in normal VCR but by concepts or topics. Enhanced navigational possibilities are required. We will see next how this can be possible.

2.5 A better way — Hypervideo

Hypervideo, a hypermedia document centered on video, is an enriched form of integrating video with other media, defining links across and inside the video, allowing more powerful forms of navigation and iteractivity. Hypervideo is not exclusively video but also integrates other kind of media enhancing the video content.

In the last years video has been integrated on the Web only as a whole and the only possible way to navigate through it was similar to a VCR, i.e., with controls to play, to stop and pause.

The inclusion of anchors inside a video has made possible to navigate through a video in different ways than the normal linear one. In a more general context, the video content does not have to be necessary educational. It could be a film and we could construct a new kind of movies where the viewer could choose at some points different navigational options or different paths that could lead to different story course or even story ends. We will see this more explained in 2.7.

2.6 What is hypervideo?

Hypervideo is an interactive presentation centered on a video but that can also include several kinds of other independent media, in a synchronized and adaptive way. They can be documents that run locally or can be constructed in order to be easily transmitted thought the Web.

Hypervideo has the potential to be non-linear, but opposed to text it is not static. Being non-linear means that the viewer can navigate through time much like navigating the Web now. Hypervideo combines the powerful impact of video with the interactivity of the Web to benefit contents transmission in many ways. At its simplest form, Hypervideo
enables users to click on an object in a video to obtain additional information in either video, graphic or text form.

In traditional hypertext, nodes, links and writing spaces provide a structure for hypertext documents. In hypervideo, the framework is complicated by the temporal and spatial nature of the medium. New structural and navigational concepts have been developed to provide a unified approach towards hypervideo.

2.7 Applications of Hypervideo

Hypervideo has a large area of applicability. Almost any application area that already uses video may benefit from hypervideo. Potential applications for hypervideo include a wide range of experimental expression, film conceptualization, training, simulation, and electronic news delivery. It is clear that filmmakers, educators, corporate trainers, and media artists can utilize the structural and navigational scheme of hypervideo in their work.

3 Technological Context

3.1 Hypermedia

A Hypervideo, as mentioned above, is a hypermedia document centered on video. Hypermedia is an extension to hypertext that supports linking graphics, sound, and video elements in addition to text elements. Hypermedia is a simple and natural extension of hypertext and multimedia: multimedia provides a richness in data types enhancing its communicational power, while hypertext provides a control structure that supports an elegant way of navigating through its data in a content based manner [17].

3.1.1 What should a hypermedia model address?

The traditional node/link model underlying most hypertext systems is unable to express temporal relations explicitly. Multimedia models, which include at most rudimentary links, are also insufficient for describing hypermedia.

In general, a hypermedia model should be able to specify how individual pieces of information relate to one another at any level. Links in hypermedia become quite complex since presentation consists on several media items and some of them can be continuous like video and audio. It is necessary for a model to specify which part of the presentation is affected on following a link.

It is also important to specify how the source of the link should transform into the destination of the link. It is fundamental to know how much information does the user leave when following a link. In the case of hypertext, the “either-or” model can work well as the reader can normally focus his attention on only one block of text. In a multimedia presentation the user can be watching a video and then follow a link to go to some additional text information while still listening to the audio, for example, a spoken commentary or soundtrack.

With respect to the presentation attributes, it is also important that the model can allow global definitions for each media type so the presentation characteristic of nodes can be set at a more general level. This global attributes would be related not to a single component but instead be associated to a class of media. This would avoid, for example
in the case of a presentation integrating several audio or video item, to have to set the volume level for each one.

3.1.2 The Amsterdam Hypermedia Model (AHM)

One hypermedia model relevant for our work and which satisfies these needs is the Amsterdam Hypermedia Model (AHM) [17, 18]. AHM is a general framework that can be used to describe the basic constructs and action common to a wide range of hypermedia systems, in particular, hypervideo. The Amsterdam hypermedia model, as described by Hardman et al. in [18], “emphasizes the importance of composition, and makes use of this for building up structured documents, while allowing the specification of presentation specifications of atomic components through the use of channels. The ability to describe temporal relations has been included, while ensuring that these are maintained separately from the structural information. Context is introduced as another important concept in hypermedia and its storage within the model is indicated”.

The main elements of this models are the atomic, composite and link components and the channel.

The **atomic component** collects all the properties that can be associated to a single media item. The properties are: duration, spatial information, style and media-independent descriptions. It also allow the specification of parts of a media item. A **composite component** allows the grouping of a number of other components into an element that can be treated in the same way as an atomic component. There are two types of composite component: temporal and atemporal. A **link component** specifies the source and destination components for following a link in hypermedia. The **channel element** collects spatial, style and data format information in a form that can be reused by multiple atomic components.

3.2 Hypervideo Model

Hypervideo, even if mainly based on video, is not uniquely video. It is a combination of several medias. We saw in the previous section that, according to AHM, our presentation consist of an integration of atomic and composite components. The media items we are going to integrate in a hypervideo, like video or images, are atomic components. The composite components do not consist on data but on information regarding its components, like synchronization and timing. At the very basis of our presentation we have atomic components, i.e, we have media items.

Due to hypervideo time-based nature, it requires different aesthetic and rhetoric consideration than traditional static hypermedia. The need for the concept of time in a hypervideo system introduces a higher degree of complexity. Synchronization between videos or other media is now required.

Making it simpler, in order to construct a hypervideo we need to specify what should be display, where and when, in other words, we should specify its content, its spatial and its temporal layout. Because of its hypermedia nature, we also need to specify the connections between this presentation and others, i.e., its links.

3.2.1 Hypervideo Content

Content consists of the media items, integrated in a simple way, as atomic components, or as a combination of them, in the form of composite components. Because it is a hypervideo we should always consider the existance of at least one video item.
These media items can be **dynamic**, i.e., that changes with time, like audio, video or animations; or **static** like still images or text. One important difference between dynamic and static media is that in static media the user defines the tempo of information acquisition while in dynamic media the tempo is set by the player.

### 3.2.2 Spatial Layout

It is usually necessary to specify where the media items should be placed in the presentation. In figure 1 we show an example of layout. In this example we are integrating an extract from the video “Touching Soap Films” where we can see a sort of a “museum” of well-known surfaces. While the video is playing in one region we integrate in another location the name of the surface synchronized with the image. We also show some additional text information in accordance to the surface being displayed.

![Figure 1: Spatial layout.](image)

### 3.2.3 Temporal Layout

The temporal layout is the description of timing of the individual parts of a presentation, that is, when are they displayed on the screen, for how long and when are they removed from the screen.
3.2.4 Hypervideo Links

According to [4], links can be established between any type of media, like any link in HTML, are unidirectional and defined at the origin. As we have introduced the factor time in this system, we can also have our links depending on time, i.e., we can have links that are only active during certain periods of time, what is very useful when we have as origin a dynamic media item.

Depending on whether we have time conditions or not, and whether we have spatial conditions or not we can have four kinds of links when we have as origin a media item with temporal and spatial dimension, like video. For the present work we will focus on the case when we have video as origin, but this can be generalized:

- **Unconditional** links are always active from anywhere on the video.
- **Spatial** links are always active and only restricted to a certain region of the video.
- **Temporal** links have the whole video region as origin but are only active during a time interval.
- **Spatio-Temporal** links have both restrictions on time and on space.

As another situation, we can have a video as destination of a link. A link can even specify a subpart of the target video by giving a time interval. This is especially useful when we have a rather long video because we can jump to a specific moment without having to “cut” the file into video segments.

3.3 Hypervideo Assembling

In order to be able to specify the what, the where and the when of a hypervideo presentation, some meta-languages have been created in the last years with the purpose of extending the capabilities of creating static hypermedia to real dynamic hypermedia. There have been some attempts to create standards due to the Web distributed nature. Some of them are HyTime ([19]), HTIMEL: HTML Time Extension for Hypervideo ([4]), HTML+TIME ([22]) and SMIL ([33]).

We will focus on this language, specially in SMIL 1.0 version because many of the players do not fully implement yet SMIL 2.0 features. We will use it to construct our example of hypervideo and we will study it in more detail in the next chapter.

3.4 Hypervideo Authoring Systems

The direction of most of the efforts on hypermedia systems development has been mostly the integration of multimedia for the Web. There are many Web authoring systems, much of them allowing insert video clips into web pages, however few really provide hypervideo functionality. Some examples are: HyperVideo [37], Movideo SDK [24] and VeonStudio.

4 Design and Development with SMIL

SMIL became a recommendation of the W3C on June 1998 and has been developed by the Synchronized Multimedia Working Group — SYMM-WG. This group includes organizations like Netscape, Philips, Real Networks, IBM, Microsoft, among others.
The Web is already a multimedia environment, but lacks a simple way to express synchronization over time. For example, with HTML we could not give instructions to “display video 1 first and 10 seconds after display Text A, when video 1 finishes, display video 2 starting at second 20 . . . ” and so on.

The major difference between SMIL and HTML is the fact that SMIL integrates the factor time and this makes possible to control timing over the media displayed and to better control the dynamic media.

SMIL allows us to integrate text, movies, still images, and sound, separately but coordinate their timing. Each media object is accessed by a relative file path or with a unique Uniform Resource Locator (URL) which means that presentations can be made of objects arriving from more than one place and that objects can be easily reused in multiple presentations. Presentations can be made that not only adjust for bandwidth constraints, but also for language (for example, English and Portuguese), or media type (text, image or video).

However, there is still a problem with presentation that includes video or audio. Most of this files, even after a encoding process to compress them (see 5.3.1), like encoding them to MPEG or MP3, still have a big size what makes them very hard to be transmitted over the Web. The streaming technology makes it easier and SMIL allows streaming media integration.

According to [39], streaming is the technique for transferring data such that it can be processed as a steady and continuous stream. Streaming technologies are becoming increasingly important with the growth of the Internet because most users do not have fast enough access to download large multimedia files quickly. With streaming, the client browser or plug-in can start displaying the data before the entire file has been transmitted. RealNetworks defines streaming media as “a method of making audio, video and other multimedia available in real-time over the Internet or corporate intranets, with no download wait and no file to take up space on your hard disk.”

SMIL presentations can be viewed through exclusive players like Grins or through others, like Real Player, which has included SMIL as a way to integrate its own Real Media files. It is also possible to see a SMIL presentation on a 4.0 browser through a plug-in like the RealPlayer G2 or the Barbizon Helio Soja Player. In this case, the player shows up as a separate window or can be embedded in a Web page. Files can be streamed using either a RealNetworks G2 Server or simple http.

4.1 The advantages of SMIL

4.1.1 Enables TV-Like Content

Television programs such as newscasts or training programs use many multimedia components. In these programs, the display of image, text and animation elements needs to be synchronized. SMIL enables this type of information to be easily expressed, it offers a new level of control over synchronized multimedia by allowing individual components of a presentation to be choreographed across a timeline in relation to each other thus allowing TV-like content to be created on the Web.

4.1.2 Integrates Independent Content

Regions in SMIL presentations can be defined to carry independent content (such as banner notices or ads), which can be quickly revised without affecting the rest of your
presentation. Furthermore, these contents do not have to be in the same server. It can be integrated by simply determining its URL.

### 4.1.3 Enhances Web Experiences

The integration of rich media like audio and video and not such as end-nodes but with the possibility of a richer navigation through them makes the web a much enjoyable experience. Sound, movement, animation and specially synchronization, allows completely new possibilities for a presentation construction.

### 4.1.4 Allows Alternative Contents

Because of the big differences between users conditions in the Web, like language, connection speed, users capabilities, SMIL developed the possibility of using alternative content. In a presentation constructed with SMIL it is possible to choose what kind of files should be played depending of the users conditions. For example, it is possible to have two alternatives videos, one with high-quality for whoever that has high-speed connection and another video with lower resolution for other users with low-speed connections. It is possible to construct on single presentation that adapts to the users language preference being able to select from different audio files, captioning or text files, with obvious progress for internationalization. We will show how we can do this in 4.2.5.

### 4.1.5 Eases Authorship

SMIL documents can be authored using a simple text editor, like Notepad, for example, following the successful model of HTML. Moreover, authors can describe a presentation using a few simple XML elements instead of having to learn a complex scripting language. “SMIL will have the same effect for synchronized multimedia as HTML had for hypertext,” predicts Dr. Philipp Hoschka, W3C Multimedia Activity Lead and Chair of the SYMM Working Group. “It will bring synchronized multimedia authoring to the masses.”

If you want to change when an audio or video component within a complex presentation begins, you can just edit the SMIL file. It is not necessary to rebuild the entire presentation from scratch.

### 4.2 Constructing a hypervideo with SMIL

To ease the understanding of how a presentation is assembled in SMIL, we will present an example of hypervideo based on an extract of the video “Touching Soap Films” [3].

As we show in figure 4 our presentation will include the video showing some of the most well-known minimal surfaces in a sort of museum, called “The History Room”, the title for the presentation and an index with the name of every surfaces. These names will show a colored background in the moment the respective surface is being shown. This presentation includes links from each surface to another SMIL file with additional information regarding the surface and these others presentations have links to go back to the first one at the exact moment when the respective surfaces is starting to be displayed.

### 4.2.1 Specifying Hypervideo Content in SMIL

SMIL allows the integration of different kind of media files, like text (.txt, .html), images (.gif, .jpg, ... ), audio (.wav), video (.mpg, .avi) and animation (flash animations) which
can be referenced by a relative file path, or a complete URL that can point to an HTTP server or, ideally, a streaming media server. It is important to note that the file formats of media, which can be referenced, depend on the player capabilities. In other words, possible file formats are implementation-dependent.

Here we show the specification of some media files:

```xml
<video id="vi" src="video/HistoryRoom.mpg"
<text src="TitleHR.html"
<img src="http://www.cmaf.pt/images/foto.gif"/>
```

4.2.2 Spatial Layout in SMIL

The spatial layout is defined within the `layout` section where we define global properties and specific attributes to each one of the regions. SMIL allows global definitions for the playback window appearance through the `root-layout` tag. It defines a rectangular area and all other regions are defined with respect to it.

```xml
<layout>
  <root-layout id="SMIL" title="SoapFilms" background-color="#FFFFFF"
              width="600" height="300"/>
  ...
</layout>
```

It allows the definition of a general background color and the dimensions of our screen. In order to define the areas where our media files will be displayed, SMIL uses the tag `region`. The `z-index` gives the stacking order (highest integer stacks on top). Regions can also have background color.
4.2.3 Temporal Layout in SMIL

The duration of a media object element can be either **intrinsic** or **explicit**.

The explicit duration is what we call the document time and can be given by the `dur` attribute. Even in the case of text, which intrinsic duration is zero we can assign a duration by:

```
<text src="schwartz.txt" region="text4" begin="3s" dur="100s" />
```

It means that the text will appear only 3 seconds after the presentation starts and will remain displayed for 100 seconds.

In order to specify a subpart of a media object we can also set the `begin` and `end` time. The `begin` attribute works for any clip or group. It can be used to start a clip at a specific point within the timeline. Additionally, we can set an `end` attribute alone or combined with a `begin` attribute:

```
<video src="SoapFilms.rm" begin="20s" end="120s" />
```

In this example, the video will only start playing 20 seconds after the presentation started and will end 120 into its part of the presentation timeline, playing a total of 100 seconds.

The two basic tags for controlling timing of the media elements are `<par>` and `<seq>`. The first one join together elements to be played in parallel. In a `<seq>` tag, media elements will play in a sequential mode, i.e., one media will only star after the previous is finished.

4.2.4 Links in SMIL

Links in SMIL are uni-directional single-headed links, i.e. all links have exactly one source and one destination resource. It is possible to have links to related media, including Web sites, by the use of two link elements: `<a>` and `<anchor>`.

The `<a>` element is similar to HTML `<a>` element. The source may have different behaviors depending on the `show` attribute. It may continue playing while another window is opened for the destination source. This is the case when `show="new"`. The source may also pause while the destination is shown in another window or the destination may replace the source. This last option is the default option.

It is also possible to specify temporal and spatial subparts of a media object element as destination of a link.

4.2.5 Adaptive Content

We have refered in [4.1.4] the advantage of allowing alternatives behaviors in a presentation. It is used to define multiple options that SMIL player will choose between at run time. How do we do this? The `<switch>` element allows the specification of various media objects, from which at most one will be played. When listing the alternative contents, the first acceptable element will be chosen, so ordering should be best first. SMIL 1.0 allows seven different test attributes and therefore, the author can adapt his presentation to other variables:

- **system-bitrate=integer** specifies available network bandwidth.
• **system-captions="on|off"** allows authors to supply subtitles, for those with hearing difficulties or learning a language.

• **system-language=list of languages names** determine the intended language group.

• **system-overdub-or-caption="caption|overdub"** selects between dubbing or subtitles.

• **system-required=extension name**.

• **system-screen-size=screen-height×screen-width** in pixels.

• **system-screen-depth="1|8|24|etc."** gives the depth of screen colour palette the player is able to display.

4.3 SMIL players

4.3.1 GRINS Player

GRiNS player was developed by Oratrix Development B. GRINS is not only a player but a complete authoring software that offers several tools to build presentations based on SMIL. The documents created by the GRiNS authoring software can also be played by other players like RealPlayer. Furthermore, Oratrix developed GRiNS/G2-Pro, and authoring tool exclusively developed for RealNetworks RealPlayer G2.

This version presents several problems on working with `<anchor>`. The `coords` attribute does not work properly so it is not possible to restrict links on space. It is not possible to jump to a subpart of the video using `<anchor>`. Oratrix Development BV was the first company releasing a SMIL 2.0 player, GRiNS/SMIL 2.0 Evaluation Player. Unfortunately, this last player is still under development and do not include yet all the new capabilities that SMIL 2.0 language provide.

4.3.2 RealPlayer

RealNetworks has developed in the last few years several products to deliver its own streaming media files, however, since version 7.0 RealPlayer started assembling various media formats, including RealNetworks own files, with SMIL. They started including SMIL 1.0 features and the player last version, RealPlayer 8.0, still includes only SMIL 1.0 and not SMIL 2.0.

At present time there are more than 180 million RealPlayers currently registered to Internet users, what makes of this player and its SMIL extensions an important option to consider when building a presentation.

RealNetworks own streaming media files include RealPix, RealText, RealAudio and RealVideo files. RealText is a RealNetworks mark-up language to format streaming text. Equivalent uses have RealPix, for streaming graphics, RealAudio for streaming audio and RealVideo for streaming video.

4.3.3 Quick Time

The QuickTime Player is an application for playing or viewing any media compatible with QuickTime. QuickTime has a built-in capability to handle diverse media. By the use of the QuickTime Plug-in it is possible to play QuickTime movies from any browser.
According to Apple’s site more than 20 million unique users have downloaded QuickTime Player.

5 Producing a Hypervideo

a hypermedia application with the inclusion of dynamic media, like hypervideo, is a new product that presents new challenges and requires new production models. Furthermore, with SMIL it is created to be mainly delivered through the widest hypermedia system, WWW, what constitute a rather new delivery and interface plataform.

Experience has always played an important role on defining production strategies and in the case of new products we do not have this experience and, therefore, this strategies are harder to define and production results are harder to predict. Estimating the development effort of a hypermedia application is an important step towards the accurate evaluation of a whole production process. There have been some research done towards this estimation[21]; however, they are still predictions not absolute results.

In this chapter, even if we cannot show a concrete defined production model for hypervideo, at least, we will try to present some outlines of the general phases on the production of this sort of hypermedia product.

We could identify the following general steps:
Step 1: Capture and Digitizing the media content for the Web.
Step 2: Editing Digital Media Content.
Step 3: Encoding Streaming Media Files.
Step 4: Integrating and Delivering Streaming Media On-line.

5.1 A Case Study: The Story of Pi

The video entitled “The Story of Pi” is part of a series of videos produced by Tom M. Apostol and James F. Blinn at the California Institute of Technology in Pasadena, California, in the context of a project called Project MATHEMATICS! (see [21]), which main goal is to attract young people to mathematics through high-quality instructional videos that show mathematics to be understandable, exciting, and with several applications to daily life.

This video has been produced together with a workbook written by Tom Apostol [2], one of the video producers. It is divided into sections, the same way the video is. In each section of the workbook, the author has summarized the important ideas of the corresponding video section and has also joint additional information that enlarges the concepts transmitted on the video. The project “Matemática em Ação” at CMAF, University of Lisbon, translated this video and the workbook into Portuguese [28].

Our case study is to produce a hypervideo named “A história do Pi” (The Story of Pi) centered on the Portuguese version of the video but provided with several links that will associate additional information, some extracted from the workbook and other written by members of the project. It will be necessary to adapt the text of the workbook to a new way of reading it. Originally, it was not to be read simultaneously with the video. The student first sees the video, at least a part of it, and then reads the workbook. In this new version, the student will have both the video and the workbook simultaneously and therefore the text has to be adapted to that fact. Some text or graphics on the workbook may become unnecessary as they are repeated on the video and it may be also necessary to change the order in which some paragraphs are presented on the workbook.
In a first stage we plan to distribute this product on CD-Rom or DVD\(^1\), so the process of streaming the files will be simplified because there are not bandwidth restrictions. The creation process is also traduced only to a digitizing and encoding process, as the video material already exists in analogue format. The recording into DVD will not be described in this study as our main purpose in this work is to develop a plan to create hypervideo. However, we are aware that this process phase is necessary for the final product to become available.

In resume, we have:

- Video tape Betacam, which is an analogue format. This tape has together the images, the sound-track and the narration in Portuguese.

- the Workbook, also in Portuguese, in printed form and as a Word file, as well as additional written material on the number “Pi”.

5.2 Resources

In this section we will describe which are the resources needed in order to produce a hypervideo in general, however, we will always mention what was needed in specific for our case study. We identified four kind of elements required: human resources, hardware requirements, software requirements and space requirements.

5.2.1 Human Resources

5.2.2 Content Providers/Authors

The content provider is the person or group of persons who supply the information to be explored in the hypervideo. The function of this person could be as an author, as a reviser (scientific reviser in our case) or editor.

In this study case, we are starting from a video production whose content provider was mainly Tom Apostol and we are expanding a bit the information he already has collected in both the video and the workbook, so, even if Tom Apostol would not be directly producing the hypervideo, he is considered as one of the content providers. The other people involved in the information handling as new content providers and/or scientific revisers are also regarded as content providers. Their function is to adapt the text to the specific needs of this new way of see the video together with text. As mentioned before, some text will need to be cut and some other will need to be changed or added.

5.2.3 Product Manager

The function of the product manager is to organize the work of all the people involved in the development of the product being also the bridge of communication between them. It is important that the product manager has enough knowledge on every one of the areas involved in the production (graphic design, programming, etc.) so he/she can better understand the work of the other elements of the team and be aware of the real difficulties and opportunities that may appear.

\(^1\)DVD (Digital Versatile Disk) is the new type of CD which storage capacity (17 Gbyte) is much higher than CD-ROM (600 Mbyte) and it can deliver the data at a higher rate than CD-ROM. With the help of MPEG and Dolby compression technologies, a DVD disk can hold hours of high quality Audio-Visual contents \[^{25}\].
In our study case, our product manager has mathematical background, and therefore, is directly involved on information handling. Due to the exploratory nature of this work, she is also directly involved on the writing of SMIL documents. She does work with graphical applications like Corel Draw and Photoshop and knows the basic techniques of video editing and capturing.

5.2.4 Designers

As most hypermedia applications, hypervideo also integrates many graphical elements, in addition to need color and style arrangements for text and backgrounds. In a general case, when the hypervideo will be transmitted through the Web, it is necessary to convert and resize them in order to be optimally transmitted. For this reason it is important to have as designer somebody with experience on the Web because the treatment of graphical components should take into account the specific needs of a good transmission through the Web.

5.2.5 Programmers

Producing a hypervideo in SMIL requires a programmer with enough knowledge in SMIL to accomplish the task. It may not be easy to find someone with this knowledge because SMIL is a very new language but a person with knowledge in HTML could easily adapt to SMIL.

5.2.6 Hardware Requirements

In what concerns hardware he can consider to possible working plataforms: Machintosh and PC(Windows). For each one there is an several option but we will include here one possible case for each one:

- **Machintosh**: Power Mac G4, Fire Wire external Hard Disk (min. 30 Gb.) Video Card Matrox RTMac, 2 Monitors 17” with resolution of 1024×768 pixels at minimum.
- **PC**: PC Pentium III at 800 Mhz with 256 Mb. of RAM, External Hard Disk (min. 30 Gb.), Video Card Matrox RT2000, 2 Monitors 17” with resolution of 1024×768 pixels at minimum.

5.2.7 Software Requirements

The necessary software is divided into 3 groups:

- **Video capture software**. It normally comes with the video card, so it depends with which card the work is being done.

- **Graphical software** like Photoshop and CorelDRAW and **Video editing software** like Adobe Premiere 6.0 or Final Cut Pro.

- **Player** RealNetworks RealPlayer 8.0.
5.2.8 Space Requirements

In this kind of hypermedia applications the biggest part of the effort is in software development. The hardware requirements do not occupy big spaces and for this reason developing the software using the hardware does not need any special space. Depending on the numbers of elements on the team, a medium-size office could be enough.

5.3 Production processes

Our goal is to produce a hypervideo that could help the user to understand what is the number \(\pi\) (pi) and which are its uses. Even if the video has contribute largely to this purpose, it has its limitations, as is mentioned in chapter 2, and for this reason we will try to enhance the power of this video adding interactivity and easy navigability. Our primary target is the group of scholar students between 12 and 16 years old. We can consider a secondary target a wide public in general with interest in mathematics.

In this production process we identify the following steps:

5.3.1 Step 1: Digitizing and encoding the video

In order to convert the analog signal of the Betacam tape into digital signal so it can be recorded on the hard disk, it is necessary to capture the video and to transform it into MPEG-2 with the appropriate software. It is also necessary to convert into digital format any other media that should be included.
Figure 4: Extending information of “Perimeter of Similar Figures”

5.3.2 Step 2: Editing the media

Besides the video, the other elements to be integrated in the hypervideo presentation come mostly from a MSWord file. The graphics in this file need to be redo in order to improve its resolution and quality. This task is performed mostly by designers but should be monitored by someone with mathematical background as these graphics symbolised mathematical concepts that should be correctly represented.

5.3.3 Step 3: Integrating it with SMIL

This is the process that takes the longest. It needs the participation of product managers, content providers, designers and programmers.

We show in figure 3 the main window of the hypervideo. It is composed by the video, and an index in both graphical and textual form. In order to show the user in which section he is, we added a small yellow border to the graphic that indicates the section being displayed at each moment. When the user clicks either on the graphic or on the text, the video jumps to the start of the chosen section. The rest of the presentation remains the same.

For each section, an specific textual index is displayed under the video screen.
5.3.4 Step 4: Testing

As any product, it has to go through an evaluation process in order to verify that the principal objectives of the production planning have been achieved. It has to be tested with users inside our primary target, that is, students between 12 and 16 years old.

After the test period, it is necessary to do the required changes and correct the problems that may have appeared. The whole production team will be necessary for this process.

5.4 Production Budget

In a general production budget there are some important elements to consider like copyrights, equipment and human resources.

Because this hypervideo is a second use of a video production we have to negotiate the rights to use this material. However, in our specific case we have the agreement of the author to use it for free due to the academic nature of our project. For this reason, we consider copyright costs as zero.

We will consider 1 week = 5 days and 1 day = 5 hours. Our working day will be considered as having only 5 hours because all the members of the team will not be exclusively dedicated to this work.

In order to summarize we present in figure 5 the time-line for the production process. The arrows show the dependencies between steps by the predecessor-successor order.

![Figure 5: Production time-line.](image)

5.4.1 Computing Costs

Taking into account the previous description on working weeks per element of the team, we can summarize human resources cost by:

<table>
<thead>
<tr>
<th>HR weeks in</th>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
<th>Step 4</th>
<th>total weeks</th>
<th>Cost/wk (Euro)</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manager</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>2</td>
<td>15</td>
<td>500</td>
<td>7,500</td>
</tr>
<tr>
<td>Programmer</td>
<td>1</td>
<td>0</td>
<td>12</td>
<td>2</td>
<td>15</td>
<td>200</td>
<td>3,000</td>
</tr>
<tr>
<td>Designer</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>500</td>
<td>3,000</td>
</tr>
<tr>
<td>Cont. Provider</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

It is important to note that the cost per week of an standard programmer in the open market is much higher than what we estimate here because, in our concrete case, we have special conditions that allow us this cost. In addition to this, due to the academic nature of our project, cost in content provider and scientific revisors are zero.
Cost in equipment (hardware+software) will depend on the platform that is chosen but it will vary between 5000 and 7000 Euro.

Therefore we can conclude that an estimation of the total cost could be around 20,000 Euro.

6 Conclusions

The main difficulty in the communication of mathematical concepts is due to one of the basic features of Mathematics: abstraction. We have seen that visualization is a powerful tool to fight against the demotivation on the student when faced to abstract concepts as it helps them to “see” what they are studying. Video has proved to be a potent media to deliver mathematical ideas in a graphical way. Unfortunately, the way video is seen is mostly in a passive mode. This way is not sufficient to deliver abstract concepts because it may not provide the student the necessary reflective moment nor is able to adapt to each student specific knowledge needs.

Hypervideo technology provides a much better way to see video as it allows interactivity and a much richer form of navigation. The possibility to get additional information if necessary will ease the comprehension of a concept, as it will avoid the lack of knowledge of the previous basic concepts necessary on the understanding of the correlated topics. With hypervideo the student can always set the pace in the process of learning a concept and we can have lessons that adapts perfectly to each students needs. If the student knows less he will have the opportunity to find out more, if he knows more he can go faster or can even see the video straight forward.

We have to take into account that with the development of the new technology and the appearance of several hypermedia products in almost any area, users are no longer willing to see video in a passive way. They will want to interact with it and therefore, educational product should also adapt to this new generation of users.

We can conclude that hypervideo is a new and optimal way to deliver education content. In the case of Mathematics, where visual dynamic images can help so much on the understanding of concepts, we can even state that hypervideo is nearly an indispensable tool.

We have tried to present in this work not only the main features and advantages of hypervideo but to introduce some of the most important tools for creating this kind of presentation. We have presented the advantages of SMIL and most of its potentialities. However, when faced with the use of players we have come to the conclusion that this language is still “too new” and therefore, software has not yet adapted completely to all its potentialities. Unfortunately, players (specially Grins and Real Player) are still developing many SMIL features and do not accomplish well all the tasks.

We have had several problems with the players when trying to develop our first prototype. As it was a new language, it was hard to discover whether is was an error on the use of SMIL syntax or it was a problem on the player behavior. Thanks to the contact with people at Oratrix technical support, we could verify that in most of the cases it was a problem on the player. Due to this fact, we were not able to construct a prototype according to all the potentialities that SMIL offers but at least we could make it perform the most important tasks.

In practice, we still have to wait for an important improvement in the players and in the conditions of transmission of media over the web. Streaming video is a possible
solution however it is not optimal yet. Even streaming video suffers for the congestion of the web and the video do not come smoothly as it has to stop several times due to traffic congestion on the net. The only way to deliver high-quality video nowadays is on DVD or by other kind of transmission rather than standard web connections. However, further research has to be done in the area of delivering streaming media because Internet is still a too important medium, both as a communication medium and because of the economic interests behind it. Especially in the case of educational content where the main purpose is to deliver it to as wider audience as possible.

Another direction for future research is in image recognition techniques that could allow clickable contents but not the way SMIL does it now, simply defined by areas of polygons. SMIL does not allow by now clicking on a moving image like a person walking. There is some software that is able to do it but with some strong restrictions by now.

We have also seen, by the last part of chapter 5, that hypervideo is an affordable application for medium or even small organizations. It does not need too much equipment nor human resources. It is a good way to improve old educational videos that were lacking of interactivity or were missing some additional content and convert them into new and more complete products that adapts to new users expectations of media.

In spite of some technical difficulties, we can assert that it is the time to start developing hypervideo products and try to deliver them in the best way possible for the moment while we expect improvement on the transmission conditions. Due to the fact that SMIL creates the hypervideo by integration of independent media, we can always develop it further and change the items that integrate it with improved or more appropriated media items.

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